

Implementation of diffraction in a spectral wave model SWAN

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LONG-TERM GOALS

To implement wave diffraction in a spectral wave model SWAN (Simulating WAVes Nearshore), in order to extend the application of the model to areas close to artificial and natural obstacles (breakwaters, peninsulas etc.).

To develop coupled wave and current models for the Baltic Sea and the Bay of Gdansk, as a tool for analysis and forecasting of hydrodynamic conditions in these areas.

OBJECTIVES

1) To foster collaboration between the SWAN Team at the Department of Civil Engineering (Delft University of Technology, Delft, Holland) and Institute of Oceanography, University of Gdansk (IOUG, Gdansk, Poland) in development of the SWAN model.

2) To attend WISE (Waves In Shallow water Environment) Group Meeting in Orillia, Ontario, Canada (April 29th-May 3rd 2001).

APPROACH

Among the research programs of the IOUG there is an ongoing project in which a coupled wave-current model based on wave forecasting models, on the one hand, and the hydrodynamic current model on the other hand, is being developed. Key researchers at IOUG involved in this work are Witold Cieslikiewicz and Agnieszka Herman.

Within the project the wind wave field in the Baltic Sea and Bay of Gdansk is modelled using the WAM (WAVE Model) Cycle 4 (WAMDI Group 1988, Komen *et al.* 1994) and SWAN Cycle III (Booij *et al.* 1999) models in a nested model chain. Both WAM and SWAN are third-generation wave forecasting models based on the balance of spectral energy and wave action, respectively. Both models run on rectangular grids in spherical co-ordinates with the inclusion of ambient currents. The wind-driven

currents in the Baltic Sea – Bay of Gdansk area are modelled with the POM (Princeton Ocean Model, Mellor 1998) model.

The meteorological forcing data used within the project are wind velocity time series provided by the Interdisciplinary Centre for Mathematical and Computational Modelling (ICM), University of Warsaw. These data are given as 3-hourly time series over a rectangular grid in spherical co-ordinates with the resolution $0.15^\circ \times 0.15^\circ$ (approximately 9 Nm in the modelled area) covering central and northern Europe. The wind velocity field is modelled by ICM based on their mesoscale implementation (UMPL) of the atmospheric and oceanic numerical model developed and used at the UK Met Office (Unified Model—UM).

There is a possibility of a relatively simple coupling between the wave model and the current model by taking the mean sea level and current outputs from hydrodynamic model and supplying them to the wave model as the “updated” bathymetry and the current field input files. This approach, however, does not account for currents generated by the propagating wind waves, interactions of wind-driven currents with the wave-induced currents as well as wave-current interactions. To this end we are planning to link the wave and current models in a more efficient way based on theoretical results of Cieslikiewicz & Gudmestad (1993, 1994), which enable to calculate the wave-induced current and the wave set-up from the modelled wave spectra.

The wave modelling in the Bay of Gdansk is one of the main goals of the wave group at IOUG. This water basin has some specific features and one of them is a very characteristic, long peninsula, which strongly influences wave propagation into the inner parts of the Bay. In certain situations (as the one depicted in Fig.1), in the vicinity of the tip of the peninsula, the diffraction effects may influence the wave field. However, both the WAM and SWAN, as most phase-averaged models, do not include diffraction. Recently, an attempt to implement diffraction in SWAN model has been made at IOUG with close co-operation of Leo Holthuijsen and Nico Booij of Delft University of Technology. The approach applied follows earlier attempts to implement diffraction in spectral wave models (Booij *et al.*, 1997; Doorn, 1997) and is based on the assumption that the mild-slope equation (Berkhoff, 1972) can be used to determine the change of propagation direction of each particular component of energy spectrum. However, the modified formulation of the model requires significant modifications of numerical techniques used in SWAN. The numerical techniques in SWAN are specifically designed for the first-order differential equation on which the SWAN model is based and adding the diffraction term increases the order of this equation to third order. Until now, no stable numerical scheme for solving the modified differential equation has been found. A new approach, proposed to the SWAN Team by the grant recipient, is as previously based on Berkhoff’s equation, but the propagation velocity in directional space is determined on the basis of mean wave parameters in a given computational grid point (thus, it is not calculated for each spectral bin separately, as it was done before).

The aim of the trip to Canada was to participate in the WISE Group Meeting. During the meeting a number of topics relevant to wave modelling in shallow water areas were discussed, together with the main problems and challenges in design and operational use of wave models, data assimilation techniques and theoretical aspects of wind wave growth and transformation. Among the problems discussed in detail between the grant recipient and other attendants of the meeting were:

- 1) Estimation of wave-induced currents in the Eulerian frame using the wind wave spectra.

- 2) Modelling of wave-current interactions and the nearshore circulation.
- 3) Nesting schemes and exchange of information between different wave models and/or model versions of different spatial resolution, e.g., interpolation techniques for boundary conditions between coarse- and fine-resolution models.
- 4) Assimilation of meteorological (wind) data obtained from numerical atmospheric models.
- 5) Verification and validation of numerical wave models against observed data; perspectives and possibilities of an exchange of such data in the future between the participants of the meeting.
- 6) Implementation of diffraction process in the SWAN model. Possible impact of taking diffraction into account for modelling wind waves in the Bay of Gdansk (especially in vicinity of the Hel Peninsula) and in other water basins with natural obstacles influencing wave propagation.
- 7) Determination of full wavenumber spectra of wind wave using CCD video cameras.

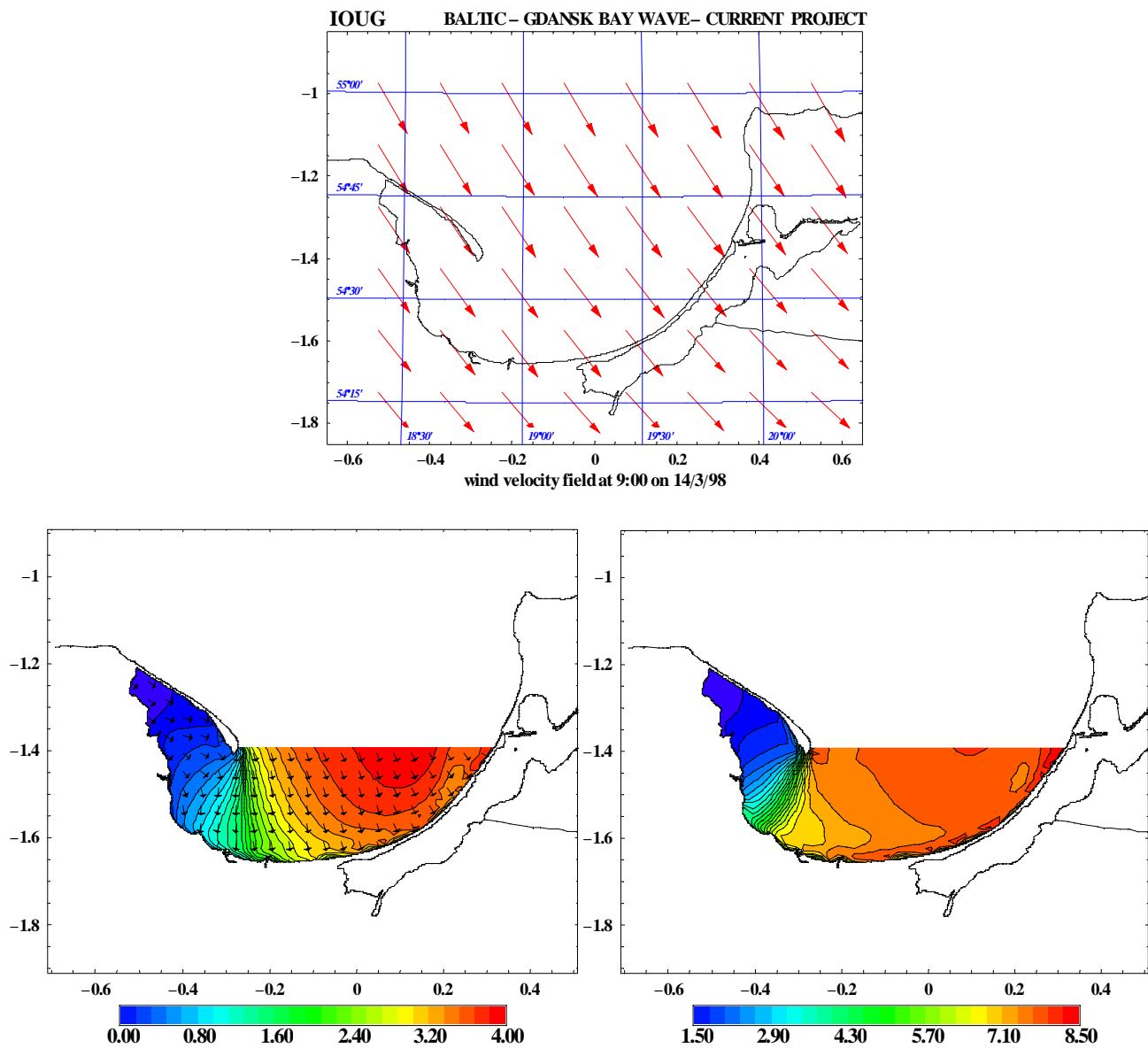


Fig.1. Wind field (top), significant wave height and wave direction (bottom left) and mean wave period (bottom right) over the Bay of Gdansk during a severe northerly storm in March 1998.

TRAVEL COMPLETED

Table 1. Summary of visits conducted under this VSP.

Person Visited	Position	Institution / Conference	Location	Scientific / Technical Purpose	Dates (mm/dd/yy)
Roop Lalbeharry	Scientist	Met. Service Canada	Orillia, Ontario, Canada	WISE Group Meeting	04/29/01-05/03/01

RESULTS

The grant recipient held discussions with Leo Holthuijsen from Delft University of Technology and with other members of the SWAN Team (IJsbrand Haagsma, Ekaterine Kriezi, Annette Kieftenburg), concerning implementation of diffraction process in the SWAN model. The following aspects of the problem were discussed:

- 1) previous (unsuccessful) attempts to include diffraction in SWAN,
- 2) possible modifications to the attempts analyzed and tested before,
- 3) further development of an approach proposed by the grant recipient, together with an analysis of the first results obtained with this approach,
- 4) some technical aspects of implementing this approach in SWAN (required modifications of the programme code),
- 5) possible impact of taking diffraction into account for modelling wind waves in the Bay of Gdansk (especially in vicinity of the Hel Peninsula) and in other water basins with natural obstacles influencing wave propagation.

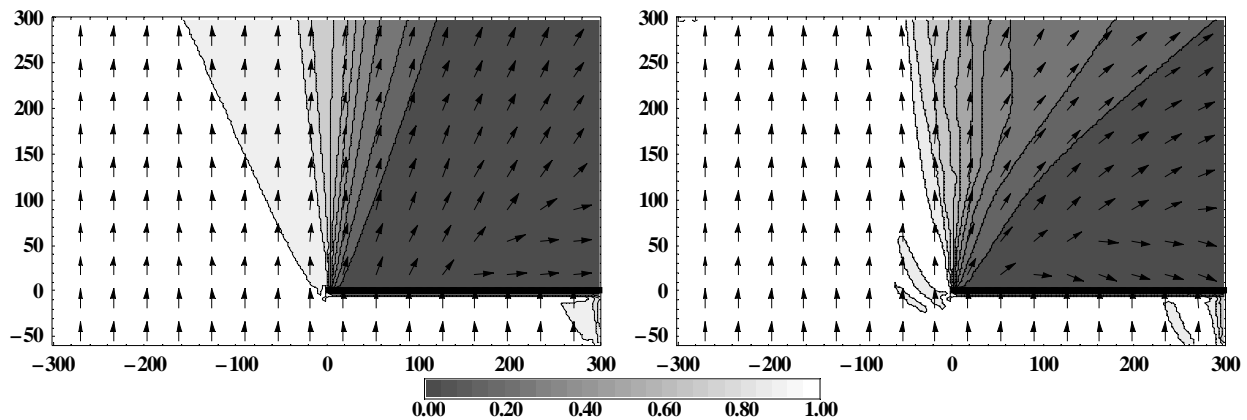


Fig.2. Spatial distribution of significant wave height and mean wave direction around a breakwater, obtained with SWAN without (left) and with (right) diffraction scheme. The incident wave direction (along the southern boundary of the domain) is 90° and significant wave height 1m.

The participants of the discussion agreed that the first results (Fig.2), obtained by the grant recipient with a new diffraction scheme (diffraction coefficient calculated on the basis of mean wave parameters, not for each spectral component separately), are in acceptable agreement with analytical results, available for simple cases studied, and that the scheme proposed is worth further studying.

Spatial distribution of both significant wave height and wave direction in vicinity of an obstacle is much better resolved by SWAN when diffraction scheme is activated. It was also agreed that, after some technical modifications and changes (e.g. better formulation of boundary conditions on obstacles), the scheme needs further testing for more complicated cases of variable bottom topography and/or complex wave energy spectra. Also a full stability analysis of the new scheme is to be performed. All the tasks mentioned above are going to be dealt with during the visit to Delft of the grant recipient, which is planned for the summer 2001.

IMPACT/APPLICATIONS

- 1) Closer collaboration between the SWAN Team and wave modelling group at IOUG, which will result in the exchange of knowledge and experience on numerical methods and design of numerical wave models.
- 2) Development of an efficient and reliable wave model for the Bay of Gdansk, as a tool for wave analysis and forecasting and a basis for further studies of wave- and current-related processes in the area.
- 3) Planned inclusion of diffraction process in the next release of the SWAN model

TRANSITIONS

- 1) The results of wave and current modelling over the Baltic Sea and the Bay of Gdansk as well as preliminary results obtained with the new scheme for diffraction will be presented at the International Conference on Coastal Engineering ICCE 2002.
- 2) The ability of SWAN to model wave conditions in areas where diffraction plays a significant role will extent the applicability of the model and provide all model users with a better tool to analyse wave conditions in such areas.

RELATED PROJECTS

Project supported by the Polish Committee of Scientific Research under contract No. 6 P04E 037 20 in which the coupled wave-current model for the Baltic Sea and the Bay of Gdansk is being developed.

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